# 3.7 Faulting and Seismicity

## 3.7.1 Existing Conditions

### *3.7.1.1 Geologic Setting*

The proposed S2GF is situated on the floor of a northeast-southwest trending river valley underlain by Holocene alluvial silt, sand, and gravel deposits. These young, unconsolidated sediments were deposited on floodplains, alluvial fans, and terraces of the Sumas River and its tributaries. They are typically stratified and well sorted, and vary in thickness from a few feet to more than 200 feet. The alluvial deposits are underlain by a thick sequence of older, more competent glacial and interglacial deposits consisting primarily of till, outwash, ice-contact deposits, and lacustrine deposits. These older sediments were deposited during as many as six glacial advances from British Columbia through the Sumas Valley and surrounding lowlands into Puget Sound. The cumulative thickness of the unconsolidated deposits is estimated to be approximately 1,200 feet at Sumas, and to decrease to about 600 feet to the southwest near Nooksack (U.S. Geological Survey 1999).

Based on soil borings (GeoEngineers 1994), there is locally at least 65 feet of soft to medium dense alluvial sand and sandy silt underlying the site area. These poorly consolidated soils are underlain by at least 35 feet of medium dense to dense sand and gravel with some silt layers. These soils are saturated, with groundwater encountered as shallow as about 4 feet below ground surface. Approximately 0.25 mile north of the site, peat deposits are present on the valley floor and glacial deposits from the most recent glacial advance are present on the low upland bounding the river valley to the northwest.

### *3.7.1.2 Faulting*

In the vicinity of Sumas, the Sumas River Valley is bounded on the southeast by Vedder Mountain and by a low upland area on the northwest. The Vedder Mountain fault is present in the subsurface along the abrupt southeast margin of the valley. As shown in Figure 3.7-1, this fault is interpreted to extend a distance of at least 65 miles, southeastward from near the Vedder River in British Columbia to north of Bellingham, and possibly as far southwest as the San Juan Islands (Gordy 1988; Dragovich et al. 1997a; and Easterbrook et al. 2000, unpublished). Easterbrook et al. (2000, unpublished) also infer a fault, which they refer to as the Sumas fault, to be present along the northwest side of the valley, as shown in Figure 3.7-1. However, to date, no surface trace of this fault has been identified, and no investigators have presented sufficient subsurface data to substantiate its existence at depth.

Figure 3.7-1

Easterbrook et al. (2000, unpublished) believe the Sumas Valley is a graben, or downdropped fault block, formed by tectonic displacement during Quaternary time on the Vedder Mountain fault and the Sumas fault. This hypothesis is based primarily on the presence of 1,000 feet of Quaternary sediments that fill the valley above bedrock and the steep escarpment along the northwest face of Vedder Mountain, across which there is about 2,500 feet of relief on the bedrock surface. They also suggest that these faults may be seismically active and associated with earthquakes that have been recorded in the area. However, no direct evidence has been documented of surface or subsurface displacement on these faults since at least the deposition of Sumas stade glacial deposits approximately 10,000 years before present (Dragovich et al. 1997a; Cox and Kahle 1999).

Although the Sumas Valley may coincide with a fault or fault system, the depth to bedrock below the valley could also be attributed, in part or wholly, to Quaternary erosion rather than Quaternary tectonic displacement. As discussed by Booth and Hallet (1993), glacial erosion by ice and subglacial water was an important mechanism in the formation of many of the deeply incised lowlands in the Puget Sound region. A preexisting fault zone may have provided a relatively weak rock mass that was more easily eroded than the surrounding area, or Quaternary displacement along one or more faults may have contributed to the bedrock relief.

Geologic information currently available is insufficient to determine whether or not the Sumas fault exists. Similarly, sufficient geologic information is not currently available to ascertain whether or not Quaternary fault activity resulted in or contributed to the formation of the present-day Sumas Valley. However, based on the absence of surface evidence for Holocene faulting, it is considered unlikely that these faults have experienced surface rupture in the last 10,000 years.

### *3.7.1.3 Seismicity*

Earthquakes are the result of sudden releases of built-up stress within the tectonic plates that comprise the earth's crust. The stresses accumulate because of friction between the plates as they attempt to move past one another. This movement and stress build up can be between plates when one moves over another such as along a subduction zone, or within the plates themselves.

Earthquakes in the Pacific Northwest originate from four different types of sources: (1) interplate earthquakes on the Cascadia Subduction Zone (CSZ); (2) intraplate earthquakes within the subducting Juan de Fuca plate as it sinks and breaks up below the North American plate; (3) shallow crustal earthquakes on faults within the North American plate; and (4) volcanic earthquakes such as those associated with the eruption of Mount St. Helens. These earthquake sources are depicted in Figures 3.7-2 and 3.7-3. The largest historical earthquakes in Washington, southern British Columbia, and northern Oregon are shown in Figure 3.7-4.

Figure 3.7-2

Figure 3.7-3

Figure 3.7-4

The CSZ is considered to be capable of generating the largest earthquakes in the Pacific Northwest. These subduction earthquakes, which originate at depths of 6 to 25 miles beneath coastal and offshore Oregon and Washington, are capable of having a Magnitude of 8 or greater. They are generally believed to occur every several hundred years; geologic evidence indicates that the most recent of these great earthquakes occurred about 300 years before present (Atwater 1987, 1992). Rogers (1988) and Heaton and Hartzell (1986) have suggested that a rupture of the entire 900-kilometer length of the CSZ could produce a Magnitude 9.1 earthquake. Analysis of historical records of tsunamis (earthquake-generated sea waves) in Japan support the interpretation that the CSZ earthquake that occurred 300 years ago was about a Magnitude 9 event. This type of earthquake would generate long-period ground motions at the S2GF site for a relatively long duration.

Intraplate seismic events in the region are considerably more widespread and frequent than the great earthquakes on the CSZ. They result from rupture within the subducted plate at depths of 20 to 55 miles below the surface. Based primarily on the historical record of intraplate earthquakes in western Washington and other subduction zones, the intraplate zone is considered capable of generating earthquakes as large as Magnitude 7.5. Historically, intraplate earthquakes have caused the greatest amount of damage in the Puget Sound region. Major intraplate earthquakes in the region have included the 1949 Magnitude 7.2 Olympia earthquake, the 1965 Magnitude 6.5 Seattle earthquake, and the 2001 Magnitude 6.8 Nisqually earthquake, all of which caused substantial property damage in central and southern Puget Sound. The northern Puget Sound region has not experienced any damaging intraplate earthquakes in historical time.

There is increasing geologic evidence that shallow crustal structures in the Puget Sound region have the potential to produce relatively large earthquakes. Based primarily on paleoseismic studies and limited historical earthquake records, shallow crustal faults in the region are considered capable of generating earthquakes as large as Magnitude 7.5. The shallow 1872 North Cascades earthquake was estimated to have been a Magnitude 7.3 (Noson et al. 1988), whereas the largest instrumentally recorded shallow crustal earthquake in the Puget Sound region was the 1996 Magnitude 5.3 Duvall earthquake. Neither of these events has been associated with a known Quaternary fault.

The Seattle and Whidbey Island faults are the most potentially significant Quaternary faults in western Washington. Although little present-day seismicity has been demonstrably linked to these faults, the Seattle fault is known to have ruptured the ground surface approximately 1,100 years ago during a Magnitude 7 to 7.25 earthquake. Other faults in the region that have recently been found to have had Quaternary displacement include the Devils Mountain fault and two faults on the northern end of Whidbey Island (Johnson et al. 2000). Also, Qamar and Zollweg (1990) mapped a suspected Quaternary fault approximately 10 miles southeast of the project site based on a linear zone of seismicity. Dragovich et al. (1997b) inferred the source of this linear trend of seismicity to be the Macaulay Creek thrust, based in part on earthquake focal mechanisms that indicated thrust movement along this zone.

Roberts (1999) and Easterbrook et al. (2000, unpublished) have recently evaluated instrumentally recorded shallow crustal earthquake data obtained by the University of Washington between 1969 and 1993 for the northern Puget Sound region. These studies identified a northeast-southwest trend of earthquake epicenters that they interpret to be associated with the Vedder Mountain fault and/or the inferred Sumas fault (discussed in Section 3.7.1.2). Based on a review of the graphic presentations filed by Dr. Easterbrook in an affidavit to EFSEC (Easterbrook 2000, unpublished), a relatively weak spatial association between earthquake epicenters and the general vicinity of the faults can be interpreted, although alternative alignments of earthquakes are equally apparent.

The focal mechanisms of the earthquakes along the trend identified by Dr. Easterbrook generally indicate that the sense of displacement associated with these earthquakes was predominantly reverse slip with some strike slip component. This displacement is not consistent with the normal slip displacement that Easterbrook et al. (2000, unpublished) inferred for the Vedder Mountain and Sumas faults, although a fault can have different senses of movement over time. Nevertheless, this apparent discrepancy, coupled with the weak spatial association of the earthquake epicenters and faults, underscores that there currently is not enough information available to either accept or reject Dr. Easterbrook's hypothesis that the faults and earthquakes are causally associated.

## 3.7.2 Changes Related to Faulting and Seismicity

An evaluation of environmental impacts pertaining to seismicity was not included in the original scope of the EIS. However, in a recent affidavit submitted to EFSEC, Dr. Easterbrook presented preliminary results of a geological and seismological evaluation that led him to believe that young faults capable of generating earthquakes bound the Sumas River Valley a short distance from the project site. In response to the concerns raised by Dr. Easterbrook, the second Revised ASC has been updated to include and in part address earthquake risks at the site. SE2 has also committed to performing additional geologic and seismic analyses prior to construction and to using the results of those analyses in the final design of the facility.

## 3.7.3 Environmental Impacts

The consequences of a distant great earthquake or a local moderate to large earthquake are significant due to the potential for earthquake-induced hazards to damage the facility or pipeline. Earthquake-related damages to engineered structures can occur from surface rupture along a fault, liquefaction of soils, slope failures, or ground shaking. The potential for each of these mechanisms to damage the S2GF is discussed below.

**Surface fault rupture.** The potential for damage to the plant site or pipeline by fault rupture is considered highly unlikely because of the lack of any evidence of geologically recent surface faulting in the project vicinity. Generally, faults that have had a surface rupture during the Holocene time (the last 10,000 years) or multiple ruptures during the

Pleistocene epoch (10,000 to 1.8 million years before present) are considered to have a potential for future fault rupture. The few known faults within the Puget Sound region that fit either of these categories are located far from the site, as described in Section 3.7.1.2.

No Quaternary faults have been previously mapped or inferred within the project boundaries (Easterbrook 1976; Noson et al. 1988; and Rogers et al. 1996). Although recent studies (Robertson 1999; Easterbrook et al. 2000, unpublished) have inferred seismic activity along two postulated nearby Quaternary faults (see Section 3.7.1.2), the inferred surface traces of these faults do not underlie any of the proposed project facilities. Moreover, the presence of the closer of these two faults (the inferred Sumas fault) is uncertain, and there is no known surface rupture along either of these faults. Lacking evidence of fault rupture during the last 10,000 years, the likelihood of a surface rupture along this inferred fault during the life of the project is considered to be very low, and if surface rupture were to occur it would not directly affect the S2GF facilities because they do not overlie the trace of the fault as inferred by Easterbrook et al. (2000, unpublished).

**Liquefaction.** Although limited subsurface investigations have been performed at the site, earthquake-induced liquefaction and associated lateral spreading and ground failures are a significant potential hazard at the site. Based on soil investigations by GeoEngineers (1994), the site is underlain by a relatively thick alluvial sequence of saturated, loose to medium dense sand and silty sand. Similarly, alluvial deposits also underlie the pipeline corridor. All of these soils are generally susceptible to liquefaction if they are subjected to strong ground motion during an earthquake.

**Slope Failures.** The project site is situated in a broad flat-lying valley. The topography on and near the site consists of stable natural slopes with less than 5 percent grade. Therefore, seismically induced slope failures are not a consideration at the site or along the pipeline corridor.

**Ground Motion.** The western Washington and southern British Columbia region surrounding the S2GF site is characterized as one of high seismic hazard due to the potential for strong earthquake ground motion. The site is in Seismic Zone 3 of the 1997 Uniform Building Code (UBC). This UBC category is next to the highest for seismic activity and greatest expected damage. The largest rational and believable seismic event that appears to be capable of occurring in this region, also known as the maximum credible earthquake (MCE), is in the range of Magnitude 8.0 to 9.5.

According to the probabilistic seismic hazard maps published by the U.S. Geological Survey (Frankel et al. 1996), the estimated peak ground acceleration for the site area is 0.20g (where "g" is acceleration due to gravity and equals 9.8 meters per second ) for a 475-year return period (i.e., ground motion with a 10 percent chance of being exceeded in 50 years) and 0.40g for a 2,475-year return period earthquake (i.e., ground motion with a 2 percent chance of being exceeded in 50 years.) However, if the Vedder Mountain fault and/or the inferred Sumas fault are capable of generating earthquakes, the probabilistic ground motions for these return periods may be higher.

### 3.7.4 Mitigation Measures

The following mitigation measures have been proposed by SE2 as part of the design and construction of the facilities to mitigate the earthquake hazards to the S2GF, gas pipeline, and transmission lines:

- A detailed geotechnical investigation would be conducted prior to final design to establish the areas and extent of liquefiable soil layers underlying the proposed plant site, gas pipeline corridor, and transmission lines.

- Additional geological and possibly geophysical investigations would be conducted to further assess the presence and seismic potential of the Vedder Mountain and inferred Sumas faults.

- Prior to final design, SE2 would perform a probabilistic seismic hazard analysis (PSHA) based on historical seismicity and site-specific geologic conditions. If definitive data regarding the potential for seismic activity on the Vedder Mountain and/or Sumas faults are still lacking when the PSHA is conducted, a logic tree approach would be used to consider alternative interpretations and fault parameters, and to design accordingly.

- As part of the final design, SE2 would develop site-specific seismic design criteria for S2GF for foundation and major equipment based on the results of the geotechnical investigation, the fault study, and the PSHA. At a minimum, the proposed facility and pipelines would be designed to comply with Seismic Zone 3 standards of the UBC or other national or State of Washington seismic design standards that supersede the UBC standards.

- Based on the results of a detailed geotechnical investigation and the ground motion estimates developed from the PSHA, site-specific design criteria would be developed prior to final design to address the risk of liquefaction. If ground instability is found to be an issue, ground modification techniques and specialized foundations for structures would be designed to mitigate liquefaction impacts. In addition to ground modification, earthquake-sensitive elements of the project could be placed on piles to protect against damage from liquefaction and ground failure. For the structures, additional reinforcement could be added to concrete, or the concrete sections could be made larger. For steel components, larger steel sections could be used, stronger connections could be installed, and more reinforcements in steel could be used where needed to withstand the design earthquake. Particular attention would be given to tanks used to store hazardous materials to ensure adequate containment.

In addition to the above mitigation measures during the design and construction of the plant, pipeline, and power transmission lines, SE2 has proposed to perform visual inspections after abnormal seismic activity. Inspectors would look for signs of incipient mass movement in those areas identified as potentially susceptible to such failures. As part of these inspections, it is recommended that areas where hazardous materials are stored also be inspected immediately following abnormal seismic activity to verify that containment systems are operating as designed.

### 3.7.5 Significant Unavoidable Adverse Impacts

In the very unlikely event the Sumas fault is found to underlie the plant site and to have ruptured in the last 10,000 years, it is questionable whether it would be feasible to economically construct the plant to provide adequate protection from the hazard of surface rupture.